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MODERN SCIENTIFIC METAPHORS OF WARFARE:
Updating the Doctrinal Paradigm

A Monograph
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Second Term AY 92-93

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	27 MAY 93	

4. TITLE AND SUBTITLE
MODERN SCIENTIFIC METAPHORS OF WARFARE: Updating the Doctrinal Paradigm

5. FUNDING NUMBERS

6. AUTHOR(S)
MAJ PATRICK KELLY III

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
School of Advanced Military Studies
ATTN: ATZL-SWV
FT LEAVENWORTH, KS 66027-6900
COM (913) 684-3437 AV 552-3437

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
SEE ATTACHED SHEET

14. SUBJECT TERMS Nonlinearity, Chaos Theory, Catastrophe Theory, Clausewitz, Culmination Point, Center of Gravity, Friction, Uncertainty

15. NUMBER OF PAGES 56

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

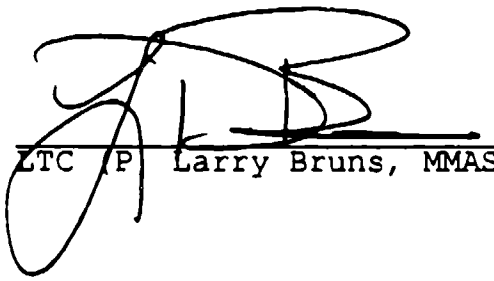
SCHOOL OF ADVANCED MILITARY STUDIES

MONOGRAPH APPROVAL

Name of Student: Major Patrick Kelly III, MSSI

Title of Monograph: MODERN SCIENTIFIC METAPHORS OF WARFARE: Updating the Doctrinal Paradigm

Approved By:



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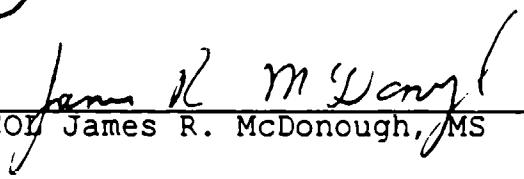

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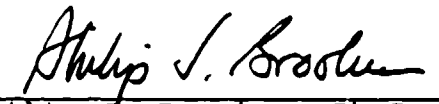

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Accepted this 14th day of May 1993

ABSTRACT

MODERN SCIENTIFIC METAPHORS OF WARFARE: Updating the Doctrinal Paradigm by MAJ Patrick Kelly III, USA, 56 pages.

This monograph examines the question can modern metaphors, based on late twentieth century nonlinear scientific thought, better explain concepts described by Clausewitz, using early nineteenth century linear scientific thought. Clausewitz recognized the nonlinearity of warfare, but described it using linear metaphors. Both warfare and science have evolved since Clausewitz. His ideas require review in light of contemporary vanguard scientific nonlinear thought.

The monograph examines the military and philosophical origins of Clausewitz ideas. Next the education and scientific background of Clausewitz are examined. Clausewitz's scientific metaphors: friction, uncertainty, chance, culminating point, center of gravity, polarity, and the trinity of three magnets are discussed as vanguard scientific thought. Modern nonlinear theories: catastrophe theory, chaos theory, and the double helix are explained and contrasted against the Clausewitzian linear scientific metaphors.

The monograph concludes that some current doctrinal concepts need to be reexamined in light of nonlinearity. The paradigm shift which recognized chaos theory requires a reexamination of the linear metaphors used to describe warfare. The current FM 100-5 would be better served exploring and incorporating some modern nonlinear metaphors. Just as Clausewitz sought the most modern scientific knowledge to help explain his ideas, modern doctrine writers must take the same risk. Especially since modern nonlinear thought may be beginning to provide the tools necessary to explain the complexity of warfare.

TABLE OF CONTENTS

Introduction.

Carl von Clausewitz originated many of the doctrinal concepts currently contained in FM 100-5, Operations. Many concepts are borrowed from the scientific debate of Clausewitz's era to articulate his theory of warfare. The concepts of momentum and electro-magnetism are used to describe warfare and are developed into the doctrinal precepts: friction, culminating point, center of gravity, and the trinity of three magnets. The paradigms of both warfare and scientific knowledge have shifted since Clausewitz's era.

Modern doctrine is based upon the Clausewitzian metaphors, but perhaps evolving scientific thought might better explore and explain warfare. Modern nonlinear theories, such as catastrophe theory, chaos theory, and the double helix, provide contemporary metaphors which may update the understanding of warfare. Clausewitz recognized the nonlinear nature of war, but explained warfare with linear scientific metaphors of his time. This monograph will explore the question: can modern scientific metaphors, based on late twentieth century nonlinear scientific thought, better explain concepts described by Clausewitz, using early nineteenth century linear scientific thought.

The monograph will begin with a brief review of Clausewitz's life and his philosophical era.

Clausewitz's military and philosophical experiences will provide the backdrop for a review of Clausewitz's education and exposure to the scientific thought of his generation. The paper will next consider Clausewitz's scientific metaphors. The concepts of friction, uncertainty, and chance; culminating point of attack and culminating point of victory; center of gravity; polarity; and the trinity of three magnets will be discussed as vanguard scientific metaphors.

Having reviewed the scientific paradigm available to Clausewitz, the monograph will turn to modern nonlinear scientific metaphors. Catastrophe theory will introduce the concept of nonlinearity and be contrasted with the Clausewitzian concept of culminating point. Next, chaos theory will be explored as an update for the concepts of culminating point, friction, uncertainty, chance, and coup d'oeil. Finally, the double helix will be discussed as an alternate model for understanding warfare. The evolution of warfare and the concept of center of gravity will be contrasted with genetic mutation and genomes. After exploring modern metaphors, the paper will conclude by reviewing some implications for modern doctrine of using a previous scientific paradigm's metaphors.

The monograph will focus on providing alternate metaphors based upon modern scientific thought which a modern day Clausewitz might use after a comparable

lifetime of reflection. The limitations of space do not allow historical examples to be provided in conjunction with the modern metaphors.

Clausewitz's Experiences.

Understanding Clausewitz's theory of war requires an examination of the significant military and political events that defined warfare as Clausewitz knew it. His experiences are better understood when viewed against the backdrop of the philosophical and scientific debates of the early nineteenth century.

First and foremost, Clausewitz was influenced by the French Revolution and the ensuing Napoleonic wars. From his first engagements as a boy of fifteen through his participation in the final defeat of Napoleon twenty-two years later, Clausewitz personally witnessed the Napoleonic campaigns impacting the Prussian state. Indeed, as Clausewitzian scholar Peter Paret noted:

> Clausewitz's military career - his public life, as he occasionally termed it - was eventful but not exceptional. In common with thousands of officers in armies across Europe, he served from boyhood on, experienced defeat and captivity as well as victory, changed his allegiance and fought against his former sovereign, survived both physical and political dangers, was awarded the usual decorations, and rose to respectable rank.[1]

Although his personal career was typical for his generation, Clausewitz's understanding and study of these momentous events provided the framework and data for his atypical theory of warfare.

To understand why Clausewitz felt compelled to articulate a comprehensive theory of war, a theory based on his extensive personal inductive experiences and deductive reasoning, it is necessary to first discuss the philosophical trends that shaped Clausewitz. Although an active participant in the Prussian military and political events during the Napoleonic era, Clausewitz was not a direct participant in the philosophical Enlightenment which presaged and accompanied the French Revolution. Clausewitz is more directly influenced by the Counter-Enlightenment or German Movement which followed.

The Enlightenment shaped the philosophical understanding of the world as Clausewitz came of age.

> War, like all fields of nature and human activity, was susceptible to a comprehensive and systematic theoretical study. In part, it could be reduced to rules and principles of universal validity and possible even mathematical certainty, for which Newtonian mechanics set the example. However, like the arts, it was also partly in flux, constantly changing, dependent on circumstances, affected by the unforeseen and incalculable, and therefore always requiring application through the general's creative genius.[2]

These ideas dominated military thinking for most of the eighteenth century. They would find voice in Clausewitz's contemporaries, Heinreich von Bulow and Antoine-Henri Jomini, who competed with Clausewitz in their attempts to articulate a theory of war. In contrast, Clausewitz, from his initial writings through his unfinished treatise, continuously criticized any

attempts to define warfare using Enlightenment ideals.

Clausewitz sought a comprehensive theory of war which would not make trivial the complexity of warfare. In modern scientific terms, he would not accept linear solutions to the nonlinear nature of warfare. This language was not available so Clausewitz articulated his theory of war using "the ideas that were the common property of his generation. Both in method and terminology he was influenced by the philosophers of the Enlightenment and of German idealism."[3]

> The world was for them [the Counter-Enlightenment (German Movement)] not basically simple but, on the contrary, highly complex, composed of innumerable and unique elements and events, and always in a state of flux. Hence their much cooler attitude to the scientific ideal embodied in Newtonian science.[4]

Without digressing into a complete philosophical exploration of the origins of Clausewitz's thinking, Clausewitz did explicitly acknowledge the influences of Machiavelli and Montesquieu on his writings. The influence of Kant and Hegel are more problematic and subject to debate. An examination of Clausewitz's education and scientific knowledge will shed some light, but not resolve the long standing debate.[5]

There is little in Clausewitz's early education to indicate future greatness. At Neu Ruppin his regimental education would include schooling in those areas considered essential for a military officer.[6] In 1801, he began the three year Institute in the Military

Sciences for Young Infantry and Cavalry Officers. The program of instruction at the Institute continued his earlier mathematical and scientific instruction while introducing tactics and strategy. The highlight of this education was Clausewitz's exposure to Scharnhorst who would become Clausewitz's principal mentor.

Clausewitz's formal education ends at this point. His tenure as a faculty, and later as Director, of the War College, as well as service as aide and tutor to the royal family, afforded him opportunities for further personal education. Paret reminds us, Clausewitz's education or outlook should not be considered unique.

> Rather, he was a typical educated representative of his generation, who attended lectures on logic and ethics designed for the general public, read relevant non-professional books and articles, and drew scraps of ideas at second and third hand from his cultural environment.[7]

Clausewitz's Scientific Metaphors.

Clausewitz's philosophical and educational background help explain the scientific metaphors which pervade his writing. Throughout his writings, Clausewitz employs a variety of metaphors from the arts, sports, commerce, and science to articulate his theory of warfare. The use of advanced scientific concepts such as electro-magnetism and friction demonstrate that Clausewitz was aware of scientific developments during his age and was not afraid to use new scientific concepts to explain his theory of war.

To understand the shifting scientific paradigm of the early nineteenth century, it is necessary to briefly examine the evolutionary and revolutionary nature of scientific thought during this age. As Thomas Kuhn explains in his book The Structure of Scientific Revolutions, scientific paradigms can be identified without agreement on a full interpretation or rationalization of the paradigm. Therefore, a scientific event or theory can be perceived as both evolutionary or revolutionary depending upon the immediate and long-term reaction of the scientific community.[8] Three scientific paradigms dominated science during Clausewitz's lifetime.

The first and most important is the mechanistic view of the world. For over one hundred years and even throughout the nineteenth century, Newton's Laws defined classical mechanics and described man's understanding of the world. The mechanical paradigm was firmly established and permeated all scientific and philosophical thought during Clausewitz's lifetime. Clausewitz's use of the metaphors of center of gravity, friction, and culmination point all reflect the mechanistic view.

The second paradigm was the "Heat as Energy" school. This paradigm had the least influence on Clausewitz; however, he does state in On War, Book One, Chapter One, "War is a pulsation of violence, variable in strength and

therefore variable in the speed with which it explodes and discharges its energy."[9] During Clausewitz's lifetime, the work of James Black, Sadi Carnot, and Benjamin Thompson laid the groundwork for James Joule's measurement of the mechanical equivalent of heat.[10]

The Heat Theory paradigm would eventually combine with the third paradigm, Electro-magnetism, to produce the theories of relativity which would replace Newtonian physics. From a scientific perspective Clausewitz actually lived during the Age of Electricity. Most of the great discoveries of electro-magnetism occurred during Clausewitz's lifetime, to include the work of Alessandro Volta, Hans Oerstad, Andre Ampere, George Ohm, and Michael Faraday. Collectively, the work of these scientists would eventually redefine physics and sustain the Industrial Revolution. During Clausewitz's life they represented exciting and practical vanguard scientific thought. It is, therefore, not surprising that an educated man like Clausewitz would augment his classical mechanical metaphors with new scientific metaphors, most notably polarity and the trinity of three magnets.

Friction.

One of the first scientific metaphors introduced by Clausewitz in On War is friction. Chapter Seven, Book One is dedicated to understanding the impact of friction on warfare. "Everything in war is very simple, but the

simplest thing is difficult. The difficulties accumulate and end by producing a kind of friction that is inconceivable unless one has experienced war."[11]

Just as classical mechanics had to contend with different forms of friction, such as air and surface, Clausewitz identified various forms of friction in warfare. "Countless minor incidents ... combine to lower the general level of performance."[12] The military machine "is composed of individuals [the least important of whom may chance to delay things or somehow make them go wrong], every one of whom retains his potential for friction."[13] In addition to the permutations of small incidents and the interaction of the many individuals participating in war, Clausewitz also recognizes danger, personal hardship, and inadequate intelligence as other forms of friction which impact warfare.

In exploring the concept of friction Clausewitz introduces a number of scientific metaphors to describe friction to include higher mathematics, the military machine, and resistant elements. These are developed from a mechanistic view of the world, even as Clausewitz attempts to explain that warfare is not so simple that it can be reduced to a mechanistic formula. "This tremendous friction, which cannot, as in mechanics, be reduced to a few points, is everywhere in contact with chance, and brings about effects that cannot be measured,

just because they are largely due to chance."[14]

Not content to just describe the impact of friction, Clausewitz provides some words of warning to a general:

> An understanding of friction is a large part of that much-admired sense of warfare which a good general is supposed to possess...The good general must know friction in order to overcome it whenever possible, and in order not to expect a standard of achievement in his operations which this very friction makes impossible.[15]

Although not explicitly stated by Clausewitz, it must be remembered that friction can also have a positive impact. Just as surface friction on ice produces melting which assists movement of heavy objects, so too war's friction can lubricate without destroying. Clausewitz's implied message to the good general is to understand both the negative and positive impacts of friction.

Friction coalesces with danger, physical exertion, and intelligence to form the atmosphere of war. In their restrictive effects (author's emphasis) they can be grouped into a single concept of general friction. Combat experience is the lubricant which Clausewitz recommends to reduce the abrasion of general friction.[16]

The concept of chance is intimately associated with the concept of friction. Given the philosophical outlook of Clausewitz's era, truth was perceived as simple and orderly. Chance impedes this truth and is therefore perceived as another form of friction. The modern paradigm of nonlinearity challenges this philosophical

truth, but was not available to Clausewitz when he described the influence of chance on warfare.

> Only one more element is needed to make war a gamble - chance: the very last thing that war lacks. No other human activity is so continuously or universally bound up with chance. And through the element of chance, guesswork and luck come to play a great part in war.[17]

Understanding the chance involved in warfare required that "probabilities be calculated in light of the circumstances."[18] Because of the subjective nature of war and ever-present moral factors, Clausewitz contends such calculations would prove inadequate.

> In short, absolute, so-called mathematical, factors never find a firm basis in military calculations. From the very start there is an interplay of possibilities, probabilities, good luck and bad that weaves its way throughout the length and breadth of the tapestry. In the whole range of human activities, war most closely resembles a game of cards.[19]

The final element of friction is the realization that uncertainty will exist in life and on the battlefield. "Although our intellect always longs for clarity and certainty, our nature often finds uncertainty fascinating."[20] Once again because war is a dynamic process which deals with living and moral forces, absolute certainty is not achievable.

> It [the art of war] must always leave a margin for uncertainty, in the greatest things as much as in the smallest. With uncertainty in one scale, courage and self-confidence must be thrown into the other to correct the balance.[21]

The concepts of chance and uncertainty are contained

in On War, Book One, Chapter One, the only chapter Clausewitz considered complete. Combined with the other Book One chapters on danger, physical effort, intelligence, and friction; it is apparent that the concepts of chance, uncertainty, and general friction represent Clausewitz's final thoughts on these issues. As such any philosophical or scientific revision which occurred during Clausewitz's lifetime is probably represented in these final thoughts.

For other scientific metaphors, such as center of gravity and culmination point, their absence from the revised Book One does not necessarily imply they are incomplete or superseded. Most likely, these mechanistic metaphors articulate original Clausewitzian ideas which were not necessarily significantly revised as Clausewitz continued to reflect upon warfare. The contrast between these classical momentum metaphors and the subsequent electro-magnetic metaphors of polarity and the trinity of magnets suggest that these concepts are older and perhaps require the rework that Clausewitz intended.

Center of Gravity.

Clausewitz opens Book One with one of his classic definitions of war. "War is thus an act of force to compel our enemy to do our will." [Clausewitz's emphasis.][22] If war is a force then it is subject to Newton's laws and can be reexpressed as War=Mass X

Acceleration or War=Armed Forces X Will. To clarify the mass component Clausewitz introduces the concept of Schwerpunkt. Schwerpunkt has a number of translations to include point of main effort or center of gravity. Since the mass of an army must be understood as a composite of the inherent physical and moral forces, center of gravity represented a useful physics metaphor to define the mass' essence.[23]

The use of the term center of gravity would have been understood by most of Clausewitz's contemporaries as a common term. There is even a suggestion that Schwerpunkt was so common that it could be considered slang. Clausewitz's use of the term could easily have been in response to another contemporary writer.[24]

Clausewitz first introduces the term center of gravity in Chapter Nine, Book Four, although the concept is implied in Clausewitz's initial metaphor of a wrestler throwing his opponent. "But since the essence of war is fighting, and since the battle is the fight of the main force, the battle must always be considered as the true center of gravity of the war."[25] This definition is later combined with another scientific metaphor, the focal point of a mirror, to reinforce Clausewitz's idea.

> The major battle is therefore to be regarded as concentrated war, as the center of gravity of the entire conflict or campaign. Just as the focal point of a concave mirror causes the sun's rays to converge into a perfect image and heats them to maximum intensity, so all forces and circumstances

> of war are united and compressed to maximum effectiveness in the major battle.[26]

Since these definitions stand alone without any further elaboration, it is possibly understood as a repudiation of a contemporary writer, like von Bulow, who might have emphasized maneuver over battle.

Clausewitz next explores center of gravity in much greater detail in Book Six, Defense. While discussing the dynamic relationship between defense and offense, Clausewitz introduces the analogy of center of gravity to more clearly illustrate his point.

> A center of gravity is always found where the mass is concentrated most densely. It presents the most effective target for a blow; furthermore, the heaviest blow is that struck by the center of gravity. The same holds true in war...Where there is cohesion, the analogy of the center of gravity can be applied.[27]

Continuing his line of thought, Clausewitz contends focus on possession of territory disperses forces while focus on the enemy's center of gravity concentrates forces.

> Our position, then, is that a theater of war, be it large or small, and the forces stationed there, no matter what their size, represent the sort of unity in which a <u>single</u> center of gravity can be identified. That is the place where the decision should be reached; a victory at that point is in its fullest sense identical with the defense of the theater of operations.[28]

Already Clausewitz is confusing his concept of center of gravity by incorporating the concepts of a decisive point and a defense theater of operations with the identification of the center of gravity.

The confusion over Clausewitz's definition of the center of gravity continues in Book Six when he describes a major battle in a theater of operations as "a collision between two centers of gravity; the more forces we can concentrate in our center of gravity, the more certain and massive the effect will be."[29] According to the earlier definition, the battle is a center of gravity, yet it consists of the clash between two centers of gravity. The confusion only grows when Clausewitz reintroduces the concept in Book Eight.

Having established the relationship between enemy forces and their clash as the center of gravity, Clausewitz then introduces additional examples of center of gravity. The Book Eight definition, "the hub of all power and movement, on which everything depends," is the definition which is incorporated into FM 100-5 Operations. The Book Eight passage continues:

> In countries subject to domestic strife, the center of gravity is generally the capital. In small countries that rely on large ones, it is usually the army of their protector. Among alliances, it lies in the community of interest, and in popular uprising it is the personalities of the leaders and public opinion. It is against these that our energies should be directed.[30]

The revision of the concept of center of gravity between Book Six and Book Eight must be understood as a reflection of the maturation of Clausewitz's thought. The original concept of center of gravity revolved around the clash of armies and focused on the concentration of

the violence of war. As Clausewitz developed his thoughts on the political nature of war and recognized limited wars as viable forms of warfare, he recognized that the concept of center of gravity had also to adjust.

In Book Eight, the conception of political and moral centers of gravity, different from the battle clash of armies, is a manifestation of the evolution of Clausewitz's thought. Without a shift in the classical mechanics paradigm, Clausewitz is unable to introduce a new analogy to clarify the difference between military centers of gravity and political or moral centers of gravity. Electro-magnetism is introduced elsewhere, perhaps Clausewitz's intended rewrite would have pursued the electro-magnetic paradigm. Another half-century will pass before the essence of mass will be reexamined and understood within the subatomic paradigm.

Dr. Schneider and LTC Izzo contend that the Book Six definition is more correct. The author must counter that the maturation of thought demonstrated in Book Eight and Chapter One, Book One, as alluded to in Clausewitz's two notes, lead me to believe that the Book Eight definition rings truer. The absence of a better metaphor causes the confusion, not the multiple definitions. Clausewitz himself caveats his own Book Six definition with the statement , "where there is cohesion." The recognition that limited warfare symbioticly degrades cohesion

justifies the natural evolution of Clausewitz's definition of center of gravity.

Culminating Point.

The concept of culminating point is another metaphor from classical physics employed by Clausewitz. Culmination's astronomical meaning is the attainment of the highest point in the sky, the meridian, by a celestial body. Culmination's mechanical meaning is the achievement of the highest point. Both meanings allude to nonlinear motion along an arc, the elliptical orbit of a heavenly body and the swinging motion of a pendulum. These meanings are both explained using the Newtonian concepts of mass, momentum, velocity, inertia, and force. A tertiary meaning of culmination is to end or conclude. In this context, the point of equilibrium achieved by a pendulum suspended between three magnets could also be considered a culminating point.

Clausewitz initially views the interaction of the defense and the offense as a zero sum competition between forces which set things in motion. If force and motion are inherent in the interaction of defense and offense then there must be a resultant momentum which culminates when confronted with friction. The revision of Book One, Chapter One introduces polarity to clarify offense and defense relationships. Polarity is a vanguard concept during Clausewitz's lifetime as the interaction of

electricity and magnetism is just becoming understood.

Unfortunately, Clausewitz's chapters on culmination were not revised. Marie von Clausewitz's footnote to Book Seven, Chapter Five, The Culminating Point of the Attack, clearly indicates that this chapter requires additional development. Additionally, Book Seven, Chapter Twenty-Two, The Culminating Point of Victory was actually intended for Book Three and placed in Book Seven by Marie von Clausewitz.

Clausewitz contends that the force of the attack is diminished by friction and time. Therefore,

> Most of them [strategic attacks] only lead up to the point where their remaining strength is just enough to maintain a defense and wait for peace. Beyond that point the scale turns and the reaction follows with a force that is usually much stronger than that of the original attack. This is what we mean by the culminating point of the attack.[31]

Likewise, even victory has a culmination point. The interactive nature of attacking and defending are influenced by the events of the battlefield which both increase and decrease strength. Superiority is the means by which victory is achieved, not the end itself. Therefore, superiority must be risked to achieve the end, victory. Risking superiority upsets the imaginary equilibrium between opponents on the battlefield. If the equilibrium is disturbed then Newton's laws demand that a culmination point exist.

> This culminating point in victory is bound to recur in every future war in which the destruction of the

> enemy cannot be the military aim, and this will presumably be true of most wars. The natural goal of all campaign plans, therefore, is the turning point at which attack becomes defense.[32]

The culminating points of the attack and of victory are useful concepts based upon classical mechanics. Clausewitz recognized that the interaction of offense and defense needed closer examination and turned to polarity to articulate some of his final thoughts on the subject. Unfortunately, the classical metaphor of culminating point did not make this same leap. Polarity represented the first use of electro-magnetism by Clausewitz to express his ideas, but it is his other use of electro-magnetism which is most remembered and least understood.

The Paradoxical Trinity of Magnets.

Clausewitz's final thoughts in Chapter One, Book One discuss the remarkable trinity of warfare. If his notes on projected revisions are correct then this may represent his ultimate thought. To explain the paradoxical trinity Clausewitz turns to vanguard scientific thought of his day, electro-magnetism. "Our task therefore is to develop a theory that maintains a balance between these three tendencies, like an object suspended between three magnets."[33]

Clausewitz's exposure to electro-magnetism can be traced to his tenure as Director of the War College and his friendship to the German physicist Paul Erman. A renowned physicist and a member of the Royal Academy of

Sciences, Erman held professorships at the University of Berlin and the War College. Erman's work on electricity and his son's work on magnetism were both known to Clausewitz. Clausewitz attended his lectures regularly for a year without missing a single lecture.[34]

> The relationship to magnetism to electricity was just beginning to be clarified in a way that made it a cutting-edge concept for its time. It is quite possible that he [Clausewitz] actually observed a demonstration of a pendulum and three magnets as envisioned in the metaphor, for he was a man of considerable scientific literacy.[35]

The appearance of the trinity of magnets and polarity in the revised Book One, Chapter One, demonstrate the late application of electro-magnetism to Clausewitz's thought. It is known that Clausewitz's understanding of warfare evolved as he worked his way through On War over a number of years. The introduction of limited wars in Book Eight demonstrate this evolution. Although there are no electro-magnetic metaphors, the re-examination of center of gravity and culminating point in conjunction with Clausewitz's evolving thought reveal an attempt to update his metaphors with his updated thought. Faraday's final understanding of the correlation of electricity and magnetism into a theory of electro-magnetism would post date Clausewitz's death. Perhaps, this helps explain why Clausewitz's attempt to demonstrate the similar correlation of politics and warfare could only be sketched using classical metaphors

and not finalized with electro-magnetic metaphors.[36]

Modern Scientific Thought.

Having explored the life, scientific paradigms, and metaphors of Clausewitz, it is time to turn to modern science. Given military experiences similar to Clausewitz, a modern Clausewitz might have experienced the strategic defeat of Vietnam, the resultant refocus of the army, and the victory of Desert Storm. The strategic victory of the Cold War against the Soviet Union might also parallel Napoleon's demise. Parallel educaticnal experiences are probably also possible. Examining the scientific paradigm will require a little study to recognize some parallels.

Just as classical physics was the long established general framework for Clausewitz, the modern general framework must include quantum physics. These ideas will dominate scientific thought. Unlike the scientific paradigms of Clausewitz's era, specialization is more pronounced in today's paradigm. As Thomas Kuhn reminds us, the institutional pattern of scientific specialization began during the early nineteenth century and recently the paraphernalia of specialization (journals, curriculum, and societies) has acquired a prestige of their own.[37] As such, a modern theorist will have a much more difficult time maintaining his scientific literacy and, even if successful, will be much

more specialized than Clausewitz. A brief survey of the last twenty-five years reveals some modern paradigms.

Within the field of physics, various Grand Unification Theories will try to unite the fundamental forces of sub-atomic physics with the cosmological observations of the universe. Within biology, the exploration of the double helix will result in bio-genetic discoveries. Within mathematics, the computer revolution will compete with pure theoretical mathematicians as computing power will provide solutions to long unattainable problems.

This paper will focus on the fields of nonlinear mathematics, physics, and biology. Catastrophe Theory and Chaos Theory are just two examples of modern nonlinear theories. Nonlinearity is currently a powerful paradigm challenging all existing science. It can almost be viewed as a philosophic and scientific revolution.

Catastrophe Theory -- Culminating Points.

The attempt to update Clausewitz using modern metaphors begins with examining the concept of the culminating point of victory and applying the modern techniques of catastrophe theory. Catastrophe theory was developed in the 1960's by the French mathematician Rene Thom. The theory went public with much fanfare in the mid 1970's and would ultimately be incorporated into the ever growing field of nonlinearity.

The essence of catastrophe theory is its ability to describe sudden change or catastrophe mathematically using calculus and geometry. Through the use of independent variables (control factors) and dependent variables (behavior variables), Thom was able to mathematically create a catastrophe manifold diagram which displayed both the smooth and catastrophic options available to a behavior variable. Depending on the number of control factors, from one to four, and the number of behavior variables, one or two, catastrophes with alluring names (fold, cusp, swallowtail, and butterfly) or daunting names (hyperbolic umbilic, elliptic umbilic, and parabolic umbilic) were created. For most readers an understanding of these multi-dimensional catastrophes requires an understanding of dimensional space beyond the standard three dimensions.[38]

Catastrophe theory provided the mathematician and physicist with an easy solution to complex nonlinear problems. Social scientists, who observed catastrophic behavior throughout the world, also attempted to apply the rigorous mathematical proof and the elegant catastrophic diagrams to their disciplines. Events which were especially susceptible to description by catastrophe theory were shifts from gradual to sudden changes, bimodal behavior, hysteresis, and divergences.[39]

Clausewitz's description of the culminating point of

victory demonstrated both hysteresis and shifts from gradual to sudden changes. Clausewitz contends that both the attacker and defender are subject to increases and decreases of strength. These changes are complex involving physical and moral forces. Using the language of catastrophe theory, increases and decreases in strength are control factors and superiority is a behavior variable. Therefore, a cusp catastrophe, two control factors and one behavior variable, describes the interaction of forces that Clausewitz sought.[40] The relative superiority of each side could then become the control factors to determine the behavior factor of victory and another cusp catastrophe could describe victory. Alternately, the increases and decreases of strength of each side could produce four control factors which could determine the behavior factor of victory using the five-dimensional butterfly catastrophe.[41]

This simplistic use of the language of catastrophe theory is intended to demonstrate alternate modern descriptions of Clausewitz's thought. The author realizes that applying the cusp or butterfly catastrophe to determine the superiority of a force would violate the spirit of Clausewitz and be subject to same accusations of the vagaries Clausewitz leveled at the geometric theories of war. However, if some speculation can be indulged, a continuation of this line of reasoning may

demonstrate some utility.

So far, catastrophe theory has done nothing more than rephrase Clausewitz with a modern metaphor. Another application of catastrophe theory is in altering the perspective of the user. Catastrophe theory attempts to apply a macro resolution to a problem. A top-down analysis using the theoretical framework of elementary catastrophes can be a useful tool. By understanding the framework, the mechanics and processes responsible for the behavior may be better understood. Catastrophe theory may better articulate the nonlinearity and interaction of relative superiority and victory by applying the framework of catastrophe. If the sudden nature of the culminating point is highlighted then some utility has been served by using this new metaphor.[42]

Clausewitz recognized the difficulty of reconciling the theory of absolute war with the historical reality of limited wars. Catastrophe theory could assist in demonstrating that equally valid solutions exist to a given problem. One solution would involve the gradual movement to superiority and victory and the imposition of will upon the opponent which absolute war predicted. But because bimodality exists within the modeled metaphor, an equally valid sudden, or catastrophic, solution demonstrated by historical example is also possible. This redefinition of the culminating point suggests that

culmination may not have to occur as there are both gradual and catastrophic options. The interaction of the complex physical and moral forces of the attacker and defender may, or may not, result in culmination because catastrophic change is only one option.

Returning to the tertiary definition of culminating point, whereby action ends, the author must depart catastrophe theory and update thought with the more contemporary notion of chaos theory. Catastrophe theory provides a viable nonlinear model to describe a component of warfare, but it cannot describe warfare itself. A more comprehensive theory of nonlinearity is required. The metaphor of a pendulum suspended between three magnets at a state of equilibrium, or culmination, is an inherently nonlinear metaphor.

Nonlinearity -- Uncertainty and Chance.

Although nonlinearity has received a great deal of study in the last twenty years, it is not a new concept. Mathematics and physics have recognized nonlinearity since the ancient Greeks. David Ruelle reminds us, "Those we now call scientists were then called philosophers."[43] Nonlinear problems were too complex to solve and those that were solvable were studied and catalogued. Solutions to nonlinear problems were attempted by ignoring the nonlinearity and solving the linear portion of the equation. The essence of nonlinear

problems is that analytical solutions are rare or nonexistent. As the Newtonian deterministic linear world view evolved into the quanta paradigm, solutions were still sought through increasingly more detailed linear analytical processes. The reductionist study of quanta retarded the study of nonlinearity for nearly a century as science continued to search for microscopic solutions which would quantify and aggregate into macroscopic solutions.

Twenty years ago, complex behavior implied complex causes. "A system that was visibly unstable, unpredictable, or out of control must either be governed by a multitude of independent components or subject to random external influences."[44] However, now that the Kuhnian paradigm has shifted and nonlinearity is recognized as an intriguing new science, new ideas suggest that simple systems and complex systems are interrelated.

> Simple systems give rise to complex behavior. Complex systems give rise to simple behavior. And most important, the laws of complexity hold universally, caring not at all for the details of a system's constituent atoms.[45]

Nonlinearity is not the panacea to solve all of science's problems; however, it does have applicability in a number of fields.

> Systems with feedback loops, delays, 'trigger effects,' and qualitative changes over time produce surprises, often abruptly crossing a threshold into a qualitatively different regime of behavior. The

> weather, fluid turbulence, combustion, breaking or cracking, damping, biological evolution, biochemical reactions in living organisms, and hysteresis in electronic systems offer examples of nonlinear phenomena.[46]

For the moment nonlinearity's impact on the social sciences remains at the level of scientific philosophy rather than quantitative science.[47] One social science field where the relationship between scientific philosophy and quantitative science has made great strides is in economics. Clausewitz recognized that as an act of human intercourse war was closest to commerce. Perhaps, this was a recognition of the nonlinear similarities. Future philosophical and quantitative strides may yet occur in the study of warfare.

Chaos Theory.

As already indicated nonlinearity is broader than chaos theory; however, chaos theory deserves some explanation of its own since its preeminence causes confusion with the broader nonlinearity.[48] Chaos theory developed through parallel work in a variety of fields to include meteorology, mathematics, and thermodynamics. As cross-fertilization between these disciplines occurred, a new science, chaos theory, was created, named by James Yorke in 1972.[49] As seen by the endnote's list of varied contributors, chaos theory has a variety of applications and a number of discipline-unique terminology which is well beyond the scope of this paper.

One of the theory's founders provides this definition, "What we now call chaos is a time evolution with sensitive dependence on initial conditions."[50] Sensitive dependence on initial conditions involves an exponential nonlinear growth. Given sensitive dependence on initial conditions, chance and determinism are reconciled by long-term unpredictability. "A very small cause, which escapes us, determines a considerable effect which we cannot ignore, and we then say that this effect is due to chance."[51] Sensitive dependence on initial conditions is also known as the Butterfly Effect; the flap of a butterfly's wing in Peking produces storms next month in New York.[52] But perhaps sensitive dependence on initial conditions is best understood from military folklore probably familiar to Clausewitz:

> For want of a nail, the shoe was lost;
> For want of shoe, the horse was lost;
> For want of a horse, the rider was lost;
> For want of a rider, the battle was lost;
> For want of a battle, the kingdom was lost![53]

Is this not the essence of Clausewitzian friction? Just as friction introduces nonlinearity into classical mechanics, it also introduces nonlinearity into warfare.

Having introduced chaos theory, a number of new metaphors are now available to assist in updating Clausewitz's thought. Two metaphors which have applicability to the already explored concept of culmination point are strange attractors and fractal

basin boundary.

Strange Attractors -- Culminating Points.

A strange attractor is best understood by an example. The point of equilibrium where the metaphoric pendulum came to rest -- culmination between the three magnets -- is in fact a "strange attractor." Strange attractors exist in a theoretical concept called phase space. Phase space turns numbers into pictures by abstracting essential information from moving parts. In phase space, knowledge of a dynamical system at a single instance collapses to a point. Charting the points over time creates a picture which helps explain the history of the system.[54]

> One advantage of thinking of states as points in space is that it makes change easier to watch. A system whose variables change continuously up or down becomes a moving point, like a fly moving around a room.[55]

A pendulum is normally perceived as swinging back and forth in a consistent arc culminating on each side. In phase space, the pendulum's arc would be perceived as a circle. Friction causes the circle to gradually shrink, so that the actual phase space description of Clausewitz's swinging pendulum metaphor is a spiral. The spiral comes to rest at the center point, a steady state with no motion. This center point is the strange attractor which attracted the dynamic nonlinear pendulum moving with friction. Even if disturbed by some outside

influence, the pendulum will eventually return to the pattern and the attractor will prevail. Thus the tertiary definition of culmination and the Clausewitzian image of suspended pendulum is a form of equilibrium predicted by chaos theory.[56]

This understanding of phase space and attractors is necessary to provide applicability to the complexity of warfare. A pendulum has two variables, position and velocity, and is describable in three dimensions. Phase space is not limited in the number of variables or the dimensions in which it can operate. Multiple dimensions are also described as degrees of freedom. Therefore, a multi-variable dynamic system with infinite variables operating with infinite degrees of freedom, a mathematical expression of the complexity of warfare, is observable in phase space. If observable, a strange attractor will be evident and just as influential as the three-dimensional pendulum example. This idea will be reexamined later, but for now let it suffice that a fundamental order, not quantifiable, but describable, can be found in the complexities of war.[57]

Fractal Basin Boundary -- Culminating Points.

The second metaphor which is applicable to the concept of culmination point is fractal basin boundary. Returning to the spiral image in the pendulum metaphor, one unique characteristic of a spiral is that the orbit

never repeats itself and never crosses itself. This concept is easily imagined in two or three dimensions; however, in multi-dimensions this same condition must be met. The orbit must never repeat itself or cross itself. To accomplish this, the orbit must be an infinitely long line in a finite area, i.e., it must be fractal.[58]

Fractal behavior is difficult to picture in this phase space description, but it is actually easy to picture in two dimensions. Fractal theory is a way of seeing infinity and measuring the "roughness" of a shape. Picture a coastline or a snowflake. There is an inherent shape and pattern, yet upon closer examination, the edge is rough not smooth. Further examination of the rough area only reveals more roughness. Aggregation reveals a smooth pattern, yet a smooth point is never achieved.[59]

This explanation of a fractal is necessary to understand the concept of a fractal basin boundary. A fractal basin boundary represents a balance between the forces of stability and instability. Images of this concept are difficult to explain, but the author will try.[60] Returning to Clausewitz's pendulum and magnets, imagine only two magnets. The pendulum can be attracted to either magnet and will eventually be attracted to just one magnet. In effect, there are two possible solutions or steady states possible instead of the previous one. Now imagine charting the movement of the pendulum as it

chooses which magnet to end with. Within phase space, a boundary exists that separates the two possible solutions. This boundary, the fractal basin boundary, is fractal and chaotic. Even if the system is not chaotic, chaos will exist at the boundary. Here then is another example of chaos, even if the system is not chaotic, the choice is chaotic.[61]

Introducing the third magnet, as Clausewitz does, the pendulum moves among the competing points of attraction gyrating in a startlingly long and intricate pattern. This pattern is sensitive to initial conditions and is effectively irreproducible. Only friction causes the pendulum to eventually settle at equilibrium between the three forces.[62] "He [Clausewitz] perceived and articulated the nature of war as an energy-consuming phenomenon involving competing and interactive factors, attention to which reveals a messy mix of order and unpredictability."[63] Clausewitz's trinity magnet metaphor captures the orderly deterministic system of the pendulum articulated by Newton's laws of motion and simultaneously reveals the chaotic nature of sensitive dependence on initial conditions.[64]

Returning to the culminating point of the attack and the culminating point of victory, it may now be apparent that these points are actually fractal basin boundaries. As Clausewitz contends, travelling beyond these points

preordains failure. In effect, there are two possible steady states, success or failure. The threshold between these two states, Clausewitz's culminating point, is a fractal basin boundary and is therefore, subject to the rules of chaos. Prediction along this boundary is impossible, but the two end states can be known.[65] Therefore, Clausewitz can say with certainty that crossing the culminating point will cause failure, but the crossing point is unpredictable and can not be "detected" with the "discriminating judgement" Clausewitz demands.[66] "The border between calm and catastrophe could be far more complex than anyone had dreamed."[67]

As these two new metaphors demonstrate, understanding the language and concepts of chaos theory is difficult, but not impossible. Another Clausewitzian metaphor, friction, and the associated concept of uncertainty can also be understood better within the framework of chaos theory.

Dissipation -- Friction.

Friction is one Clausewitzian metaphors which has so many everyday applications that contemporary users are very comfortable with what was vanguard thought for Clausewitz. Clausewitz recognized that there was some positive value to friction on the battlefield. The concept of dissipation may be a chaotic substitute for friction. Already, friction, the mechanistic impediment,

has introduced nonlinearity. Within thermodynamics, dissipation serves the same function. Thermodynamics, like mechanics, was explained by classical physicists using solvable linear equations and assumed away or ignored the nonlinear portions.

Thermodynamics is another scientific paradigm which post dates Clausewitz. It was only recently the implications of nonlinear science on thermodynamics received greater attention. Thermodynamics provides an attractive substitute for the mechanistic view of warfare ascribed to Clausewitz. Many of the same characteristics are included, but thermodynamics also provides a macroscopic view of a system which incorporates flow. Flow represents a continuous time system, while a dynamic system concerns a discrete time. After all, is not warfare, admittedly dynamic, just another measure of the flow of time over a discrete period. The difference between discrete time and continuous time introduces the concept of scaling, which will shortly be explained. Therefore, metaphors describing ebb and flow of battle or warfare probably should include thermodynamic ideas.[68]

The significance of chaos theory was its ability to tackle the problem of turbulence. Turbulence was a nonlinear problem beyond classical physics' explanation.

> Turbulence is a mess of disorder at all scales, small eddies within large ones. It is unstable. It is highly dissipative, meaning that turbulence drains energy and creates drag. It is motion turned

random.[69]

If thermodynamics is used to describe warfare, something unavailable to Clausewitz, but built upon the same principles, then three more chaotic metaphors, have applicability: turbulence, dissipation, and scaling.

Scaling -- Uncertainty.

Turbulence and dissipation can not be discussed without a more detailed divergence into thermodynamics, once again beyond the scope of this study. However, scaling introduces two appropriate concepts self-similarity and geometric convergence. These concepts introduce the notion of an underlying order contained within randomness. Self-similarity looks at the whole and sees copies of itself at various scales. Geometric convergence mathematically proves that scaling is occurring. Scaling proves that "some quality is being preserved while everything else is changing."[70]

Here then is a chaotic reexpression of one of Clausewitz's fundamentals. If war is "a continuation of political intercourse, carried on by other means," then scaling and self-similarity predict that violence will be contained within politics and likewise politics will be contained within violence.[71] The relationship of the two concepts can not be perceived as linear, but rather as a chaotic whole which can never be divorced regardless of the scale at which it is studied. Events may be locally

unpredictable, but there is a global stability.

Another way of expressing this is to recognize that the ends-means relationship that Clausewitz articulates for politics and war is not a linear function. An interactive, feedback process is intrinsic of war. Since feedback loops are a form of sensitive dependence on initial conditions, this relationship is inherently chaotic.[72]

Seeing Uncertainty -- Coup D'oeil.

One final thought on the flow of time is its implication on uncertainty. "This transition from uncertainty to near certainty when we observe long series of events, or large systems, is an essential theme in the study of chance."[73] In a chaotic system, both a long series of events and large systems will reveal an underlying order which may be perceived with certainty. Deterministic chaos and predictable chaos can coexist in the same system. Certainty may not be quantifiable, but it is discernable. Restated, this is the heart of Clausewitz's concept of coup d'oeil.

For Clausewitz, coup d'oeil is the first component of military genius, "an intellect that, even in the darkest hour, retains some glimmerings of the inner light which leads to truth."[74] Clausewitz's concept of truth is directly attributable to his philosophical era. "Truth resides in the simple (and thus the stable, regular, and

consistent) rather than in the complex (and therefore the unstable, irregular, and inconsistent)."[75] With the shift in the scientific paradigm, simplicity within complexity and complexity within simplicity, a new vision articulates the truth that Clausewitz's coup d'oeil must discern.

Chaos theory can be used a number of ways to provide a commander coup d'oeil, to include: recognizing strange attractors, maintaining the correct degree of freedom, recognizing scaling, and recognizing the fractal basin boundary. Seeing these concepts with vision is obviously difficult. Since strange attractors, scaling, and fractal basin boundaries have already been discussed, some points on degrees of freedom are appropriate.

Vision in another dimension, or degree of freedom, is very difficult, but not impossible. Recognizing and solving a critical variable is a form of degree of freedom vision. Synchronizing the effects of varied forces or weapon systems when no one else can is a form of degree of freedom vision. The "longer breath," allowing time to flow, is a form of degree of freedom vision. The ability to recognize importance separates the seer from most. Perhaps Clausewitz captured chaotic vision when he said, "the quick recognition of a truth that the mind would ordinarily miss or would perceive only after long study and reflection."[76]

Double Helix -- Center of Gravity.

Leaving the realm of mathematics and physics, it is time to explore an alternate metaphor for the concept of center of gravity. Clausewitz described warfare using mechanistic metaphors, but recognized that warfare was an inherently organic endeavor. The influence of the developing German Counter-Enlightenment ideas stressed the diversity and living nature of human reality, its organic nature.[77] Modern biology and genetics now understand that the structure of deoxyribonucleic acid (DNA), the double helix, is essential to any study of organic behavior. If warfare is truly organic, then the double helix may contain a more appropriate metaphor for the "hub of all power."

One immediately attractive aspect of the double helix is the interaction of the two strands. This simple visual metaphor, which is chemically complex, captures the interactive nature of warfare. Without the correct interaction between the strands, the helix cannot be formed. Likewise, Clausewitz contends "war, however, is not the action of a living force upon a lifeless mass (total nonresistance would be no war at all) but always the collision of two living forces."[78] Therefore, the interaction between military forces can be perceived to define a double helix of constant interaction.

If warfare can be viewed organically using the

double helix metaphor, then the "hub of all power" must be contained within the double helix. DNA is composed of the basic chemical elements, mostly carbon, nitrogen, oxygen, and hydrogen atoms. There are only four chemically stable bases which these elements form: adenine, thymine, guanine, cytosine. All known organic life consists of permutations of these four bases. Additionally, only two base-pairs, adenine-thymine and cytosine-guanine, combine to form the connections between the strands of the helix. If one base is known then its corresponding base on the other strand is also known.[79]

The combinations of the four bases along a single strand are called genomes. Over the course of time, all of evolution is articulated within these genomes. With billions of random bases within DNA, these genomes represent an underlying order.

> It has been shown that DNA consists of a long chain of elements belonging to four types, which may be represented by the letters A, T, G, C. Heredity, therefore, consists of long messages written with a four-letter alphabet. When cells divide, these messages are copied, with a few errors made at random; these errors are called mutations.[80]

Mutations, carried along within the genetic message, are the defining feature of DNA and genetics. Mutations are as complex as the creation of a new species and as simple as the selection of eye color. Modern genetic research concentrates on locating and manipulating an appropriate genome which governs behavior. Genetics focuses on the

"stream of order" within the sea of disorder.[81]

In order to discuss order in the disorder of warfare, Clausewitz identified three components in his paradoxical trinity: violence, chance, and policy. Peter Paret in Clausewitz and the State adds a fourth fundamental force, genius. "When Clausewitz does discuss tactical details he tries to do so on the basis of the concepts of violence, chance, genius, and politics that underlie his view of war."[82] Given four fundamentals, rather than three perhaps their interaction can also be articulated using the metaphor of DNA bases and genomes. The mechanistic center of gravity would be replaced by the organic DNA double helix genome.

As already suggested, coup d'oeil is the first component of genius and can also be thought of as degree of freedom vision. Chance is also already shown to require reexamination in light of chaos theory. Perhaps then, these two fundamentals could be combined with the other fundamentals to create base-pairs, genius-violence and chance-politics, (or genius-politics and chance-violence). If the organic metaphor holds valid, then these base pairs would provide a chaotic and deterministic base-pair model which would define the interaction of warfare. To extend this analogy much further in this direction would once again violate Clausewitz's spirit, but recognizing a structural chaotic

relationship in a fundamental metaphor only reinforces the chaotic nature of warfare.

Just as life has evolved from creation through heredity, warfare has also evolved over time. The genomes which define the essence of warfare would also mutate over time and maintain a record of their mutation. Center of gravity can now be seen as the critical genome which defines a particular war. The mutation of the bases which result in evolution over time helps explain some of the discrepancy over the various definitions of center of gravity.

Due to mutation the army and battle permutations of the violence base, which Clausewitz considered a center of gravity, may have evolved. The army and battle remain critical and in the absence or negation of other variables may prove to be the decisive element. An example of this is the relationship between artillery, air power, and nuclear weapons. At different points in time each was the decisive component of war and was clearly recognized as a center of gravity. In the absence of nuclear weapons and air power, artillery might reemerge as the critical genome or center of gravity.

Permutations of the politics, chance, or genius base could also define a particular genome which would currently be recognized as centers of gravity. The Clausewitzian examples of capitals, alliances,

leadership, and public opinion can all be defined through combinations of the four fundamental forces or defined as genomes rather than centers of gravity. Remember that within the billions of repetitions of the four fundamentals, a critical genome may only contain a small section with the critical mutation.

One final thought on substituting genomes for centers of gravity involves advances in genetics. Recent ideas suggest that cancers may be caused by the failure to turn off a mutation rather than the turning on of a mutation. These converse ideas may have implications for the debate about the indirect approach and critical vulnerabilities. Rather then viewing a center of gravity as a source of strength, perhaps it is better understood as not a source of weakness. Planning which captures this thinking may resolve the debate between critical vulnerabilities and centers of gravity.

Implications and Conclusions.

Summarizing the impact of nonlinear metaphors on modern doctrine must begin with an understanding that war is nonlinear. This nonlinearity is not, however, the nonlinear operations described in the 1986 edition of FM 100-5, Operations. This manual focusses on the rapid movement of linear battle lines and the "intermingling of opposing forces ... blur[ing] the distinction between front and rear" in high- and mid-intensity conflict.

Likewise, the term "chaos" is incorrectly employed when FM 100-5 describes high- and mid-intensity battlefields as "likely to be chaotic, intense, and highly destructive."[84]

The newest edition of FM 100-5, Operations corrects the misapplication of nonlinear metaphors, but fails to highlight nonlinearity in its discussion of warfare. Indeed, the phrase "nonlinear operations" is dropped from the manual. In addition, when the new manual discusses the tempo of battle, "the battlefield has become more complex, dynamic, and lethal," is substituted for the previous chaotic phrase.[85]

The new manual paraphrases Clausewitz's paradoxical trinity. "The relationship between the government, the people, and the military is profound."[86] Profundity completely misses the chaotic nature of warfare which the metaphor of the three magnets actually describes. The continuous interaction of the three groups is iterative and chaotic. Sensitive dependence on initial conditions must be understood for each group and for the interaction of the three groups. The new manual misses an opportunity to update its understanding and use of the magnet metaphor. The prosecution of a war must be understood as chaotic; yet possibly orderly, with observable if not achievable, end states constantly subject to the underlying structure of chaos theory.

Centers of gravity and culminating points are incorporated in existing and emerging army doctrine as concepts of operational design. With the addition of the other concepts of operational design, lines of operation, and the newly included decisive points, these key concepts "guide theater planners in their efforts."[87] These concepts once again describe the linear battlefield ignoring the evolution of warfare and science. The discussion of these concepts alludes to the chaotic nature of warfare, but fails to articulate warfare in nonlinear language. Using the most modern language would further the understanding of these concepts and our understanding of warfare.

Updated language for army doctrine writers should describe how interaction, friction, and chance all generate chaos in warfare. Chaos should not be perceived as a daunting obstacle to be avoided, because chaos is locally unpredictable, but globally stable. Chaos theory and the other nonlinear theories provide some new metaphors to help explore and explain warfare's chaos.

Through our doctrine writers we continue to view warfare linearly. Clausewitz recognized warfare's nonlinearity. His metaphors attempted to articulate concepts one hundred and fifty years before science could provide the appropriate metaphors. "The concepts and sensibility recently emerging in nonlinear science can be

used to clarify not his [Clausewitz's] confusion, but our truncated expectations for a theory of war -- namely that it should conform to the restrictions of linearity."[88] Our understanding of warfare must grapple with these vanguard scientific notions, just as Clausewitz adopted electro-magnetism as more descriptive than classical physics.

Friction, culmination, center of gravity, coup d'oeil, uncertainty, and chance were considered vanguard notions to describe warfare during Clausewitz's era. For others, like Jomini, geometric precision and genius described warfare. Nonlinearity is a component of the unique description Clausewitz articulated.

Today's theorists and doctrine writers must continue to explore the applicability of nonlinearity to warfare. Catastrophes, fractals, fractal basin boundaries, self-similarity, bifurcation, strange attractors, turbulence, thermodynamics, geometric convergence, degrees of freedom, the double helix, bases, base-pairs, heredity, and genomes all provide potential nonlinear metaphors. The list can appear daunting, especially since many of the concepts involve abstract mathematical, physical, or biological definitions. The complexity of warfare deserves the most descriptive metaphors. Future theorists of war would do well to consider the applicability of modern nonlinear scientific metaphors.

ENDNOTES

1. Peter Paret, Clausewitz and the State (New York: Oxford University Press, 1976), 5.

2. Azar Gat, The Origins of Military Thought: From the Enlightenment to Clausewitz (New York: Oxford University Press, 1989), 139.

3. Paret, Clausewitz and the State, 84. Using the language of his day, Clausewitz extensively considered the interaction of the art and science of the profession of warfare. Dissecting war in one realm without due consideration of the complexities of the other was a sin Clausewitz could not tolerate.

4. Gat, The Origins of Military Thought, 142.

5. Further information on Clausewitz's philosophical influences is beyond the scope of this monograph. Philosophical influences and issues will only be discussed when they impact upon the scientific debate. For more information the following books are recommended: The Origins of Military Thought: From the Enlightenment to Clausewitz by Azar Gat, Philosophers of Peace and War: Kant, Clausewitz, Marx, Engels, and Tolstoy by W.B. Gallie, Clausewitz: Philosopher of War by Raymond Aron, and Clausewitz and the State by Peter Paret.

6. Paret, Clausewitz and the State, 53. A list of courses includes arithmetic, geometry, trigonometry, principles of mechanics, some knowledge of optics, mathematical geography, political geography, physical geography, and Prussian and German history.

7. Ibid., 151.

8. Thomas S. Kuhn, The Structure of Scientific Revolutions (Chicago: The University of Chicago Press, 1970) 43, 66-68.

9. Carl von Clausewitz, On War, ed. and trans. by Michael Howard and Peter Paret. (Princeton, NJ: Princeton University Press, 1976) 87.

10. George Gamow, Biography of Physics (New York: Harper & Row, 1961) 93-97. Transformation of energy would later be expressed using the laws of thermodynamics. During Clausewitz's lifetime, the focus was on understanding heat as a fluid and later as motion. Further exploration of the second paradigm is not continued because the majority of the breakthroughs would post date Clausewitz.

11. Carl von Clausewitz, On War, 119.

12. Ibid.

13. Ibid.

14. Ibid., 120.

15. Ibid.

16. Ibid., 122.

17. Ibid., 85.

18. Ibid.

19. Ibid., 86.

20. Ibid.

21. Ibid.

22. Ibid., 75.

23. This paragraph is a restatement of the lecture provided to the author by Dr. James Schneider. The ideas are also contained in article "Clausewitz's Elusive Center of Gravity," coauthored by Dr. Schneider and Lawrence Izzo from the September 1987 edition of Parameters.

24. Michael Inman, The Tactical Center of Gravity: How Useful is the Concept? (Fort Leavenworth, KS: School of Advanced Military Studies, 1990) 5.

25. Clausewitz, On War, 248.

26. Ibid., 258.

27. Ibid., 485-486.

28. Ibid., 487.

29. Ibid., 489.

30. Ibid., 595-596.

31. Ibid., 528.

32. Ibid., 570.

33. Ibid., 89.

34. Paret, Clausewitz and the State, 310.

35. Alan Beyerchen, "Clausewitz, Nonlinearity, and the Unpredictability of War," International Security, 17, no. 3 (Winter 1992/93): 71.

36. The author feels compelled to reemphasize the intellectual ability of Clausewitz. Not only is he wrestling with the complexities of warfare, he is also attempting to translate complex thought and theory from another profession. He has only a layman's knowledge of electro-magnetism, yet he is not afraid to attempt to make relevant applications to his body of work.

37. Kuhn, The Structure of Scientific Revolutions, 19.

38. Alexander Woodcock and Monte Davis, Catastrophe Theory (New York: E.P. Dutton, 1978) 43-57.

39. Alexander Woodcock, Application of Catastrophe Theory to the Analysis of Military Behavior (The Hague: SHAPE Technical Center, 1984) 5.

40. Woodcock and Davis, Catastrophe Theory, 45. This book provides the following definition of a cusp catastrophe, "The cusp catastrophe occurs in systems whose behavior depends on two control factors. Its graph is three-dimensional, a curved surface with a pleat."

41. Woodcock, Application of Catastrophe Theory to the Analysis of Military Behavior, 10,30. The equations for these problems follow. The cusp catastrophe has a potential function of:
$V = x^4/4 + ax^2/2 + bx$
and the catastrophe manifold diagram is given by:
$dV/dx = x^3 + ax + b = 0.$
The butterfly catastrophe has a potential function of:
$V = x^6/6 + cx^4/4 + dx^3/3 + ax^2/2 + bx$
and the catastrophe manifold diagram is given by:
$dV/dx = x^5 + cx^3 + dx^2 + ax + b = 0.$
Where a,b,c, and d are control factors and x is a behavior variable.

42. Ibid., 6.

43. David Ruelle, Chance and Chaos (Princeton, NJ: Princeton University Press, 1991) 4.

44. James Gleick, Chaos: Making a New Science (New York: Viking, 1987) 303.

45. Ibid., 304.

46. Beyerchen, "Clausewitz, Nonlinearity, and the Unpredictability of War," 63.

47. Ruelle, Chance and Chaos, 79.

48. For the purpose of this paper the two terms are interchangeable.

49. Gleick, Chaos, 66. A more complete listing of the major contributors to the evolution of chaos theory can be found in either Gleick's book or David Ruelle's Chance and Chaos. Some of the key players and their discipline include nineteenth century mathematician Jules Henri Poincare, meteorologist Edward Lorenz, topologist Stephen Smale, biologist Robert May, mathematician James Yorke, economist Benoit Mandelbrot, mathematical physicist David Ruelle, physicist Mitchell Feigenbaum, experimental physicist Albert Libchaber, and many others.

50. Ruelle, Chance and Chaos, 67.

51. Ibid., 48. This sentence, made by Jules Henri Poincare in the late nineteenth century, remained undiscovered for almost one hundred years.

52. Gleick, Chaos, 8.

53. Ibid., 23.

54. Ibid., 134-135.

55. Ibid.

56. Ibid., 136-137.

57. Ibid., 134-137.

58. Ibid., 139.

59. Ibid., 98-100. Another description of fractal involves bifurcation. Observing the choices of a nature reveals bifurcation. The forking of nature is revealed in the elegance of a tree or a single leaf. Rivers meander according to the rules of bifurcation. The never ending choices of bifurcation produce fractal behavior.

60. Ibid., 233-236. A more detailed explanation can be found using James Yorke's hypothetical pinball machine, a blender mixing a cake, and images of fractal basin boundaries.

61. Ibid., 235.

62. Beyerchen, "Clausewitz, Nonlinearity, and War," 69-70.

63. Ibid., 70.

64. Ibid.

65. Gleick, Chaos, 234-235.

66. Clausewitz, On War, 528.

67. Gleick, Chaos, 234.

68. The four fundamental forces of thermodynamics are pressure, volume, chemical composition, and temperature. Like Newton's laws, there exists a body of knowledge which includes the Laws of Thermodynamics. An alternate metaphor which is beyond the scope of this paper might try to correlate these fundamental forces with warfare. For example, pressure could equate to will, volume to battle space, chemical composition to policy, and temperature to armed strength. The beauty of such an equation is that besides describing a system's entropy or randomness it would also not violate chaos theory.

69. Gleick, Chaos, 122.

70. Ibid., 172.

71. Clausewitz, On War, 87.

72. Beyerchen, "Clausewitz, Nonlinearity, and War," 68.

73. Ruelle, Chance and Chaos, 5.

74. Clausewitz, On War, 102.

75. Beyerchen, "Clausewitz, Nonlinearity, and War," 61.

76. Clausewitz, On War, 102.

77. Gat, The Origins of Military Thought, 174.

78. Clausewitz, On War, 77.

79. James Watson, The Double Helix (New York: Antheneum, 1968) 190-203. Although the emphasis of this paper is the comparison of center of gravity with the organic metaphor of genome, another interesting exploration is the base-pair. If four fundamental forces can be defined using two base-pairs, then these base-pairs may be correlated to Sun Tzu's normal (cheng) and extraordinary

(ch'i) forces. "In battle there are only the normal and extraordinary forces, but their combinations are limitless; none can comprehend them all." Sun Tzu, The Art of War, trans. by Samuel Griffith. (Oxford: Oxford University Press, 1971) 91-92.

80. Ruelle, Chance and Chaos, 6.

81. Gleick, Chaos, 299. Use of the water metaphor may bring to mind Sun Tzu's similar use to describe the complexity of war. "And as water has no constant form, there are in war no constant conditions." Sun Tzu, The Art of War, 101.

82. Paret, Clausewitz and the State, 315. Exploring the existence of a fourth fundamental component is beyond the scope of this study. The assumption that such a component can exist is therefore made without proof at this time. Part of the proof rests in an exploration of the Kantian and Hegelian influences on Clausewitz. The articulation of warfare as a trinity can be viewed as an acceptance of a world view which emphasized the trinity as a component of the natural order of reason or as the synthesis of a dialectic. The other portion of the proof rests on the belief that given a different fundamental equation, such as thermodynamics, or an exposure to the four fundamentals articulated in micro-biology, Clausewitz might have revised his trinity to include the fourth element of genius which he obviously recognized and discussed, but failed to separate in his trinity metaphor.

83. US Army, FM 100-5, Operations (Washington, DC: Department of the Army, 1986), 2.

84. Ibid.

85. US Army, Final Draft FM 100-5, Operations (Washington, DC: Department of the Army, January 1993), 1-3.

86. Ibid., 1-4.

87. Ibid., 7-9.

88. Beyerchen, "Clausewitz, Nonlinearity, and War," 87-88.

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